Faults and Fault Behavior at All Scales

Greg Beroza

Long Range Science Plan for Seismology (LRSPS) Workshop
September 19, 2008 Lakewood, CO

NSF Charge to IRIS

"The IRIS Consortium will consult broadly with the research community to develop a new long-range science plan for <u>global</u> seismology that will guide potential future improvements and enhancements to the IRIS facilities. The Board of Directors of the IRIS Consortium will develop a plan for carrying out this review and submit the plan to NSF by March 31, 2007."

I'm going to talk about <u>local</u> seismology. I think most seismological breakthroughs will come from local observations.

What can you "see" with seismology?

→ Increasing Resolution →

Point Source	Fraunhofer	Far-Field	Near-Field
	(large λ, Δ)	($\lambda << \Delta$)	

Location

Moment — Slip Distribution (increasingly complete) →

Mechanism

Moment-Rate

What can you “see” with seismology?

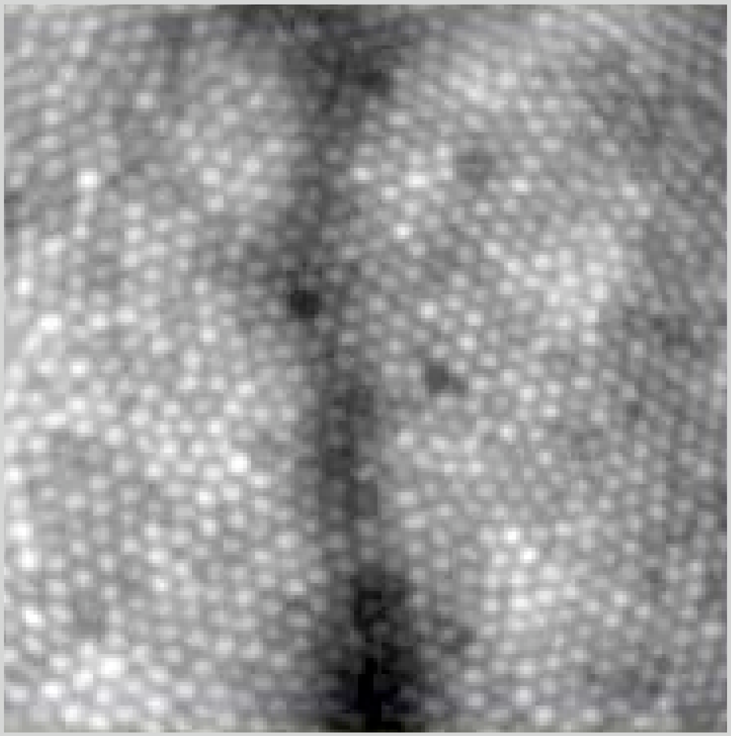


Image of a Retina

Need real arrays - your retinas have:

~120 million rods (high-gain)

~6 million cones (broadband)

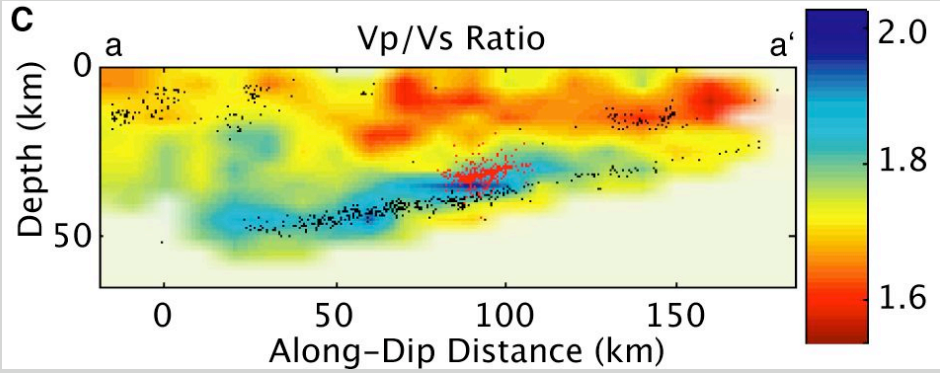
Lots of sensors (20 times as many high-gain as broadband)

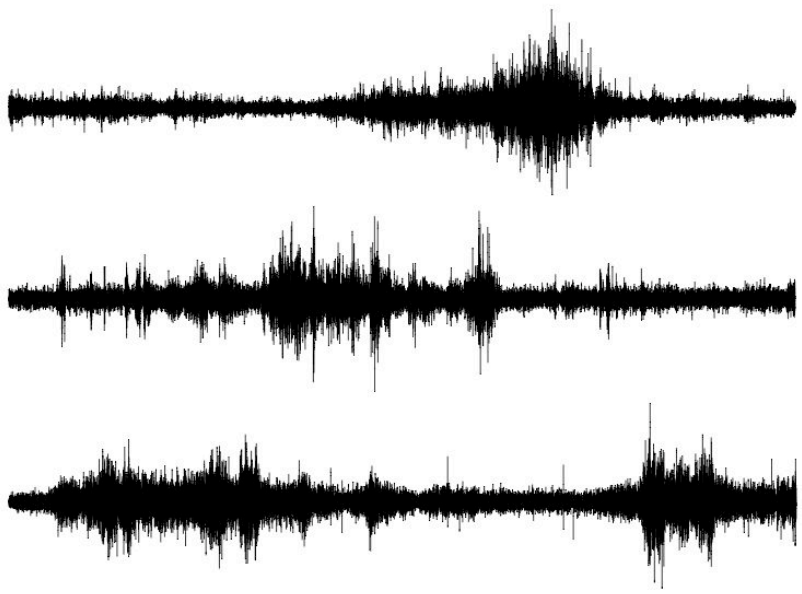
The 1995 M 6.9 Kobe Earthquake

~6000 fatalities, ~$120 billion in damage.

Tremor Mechanism

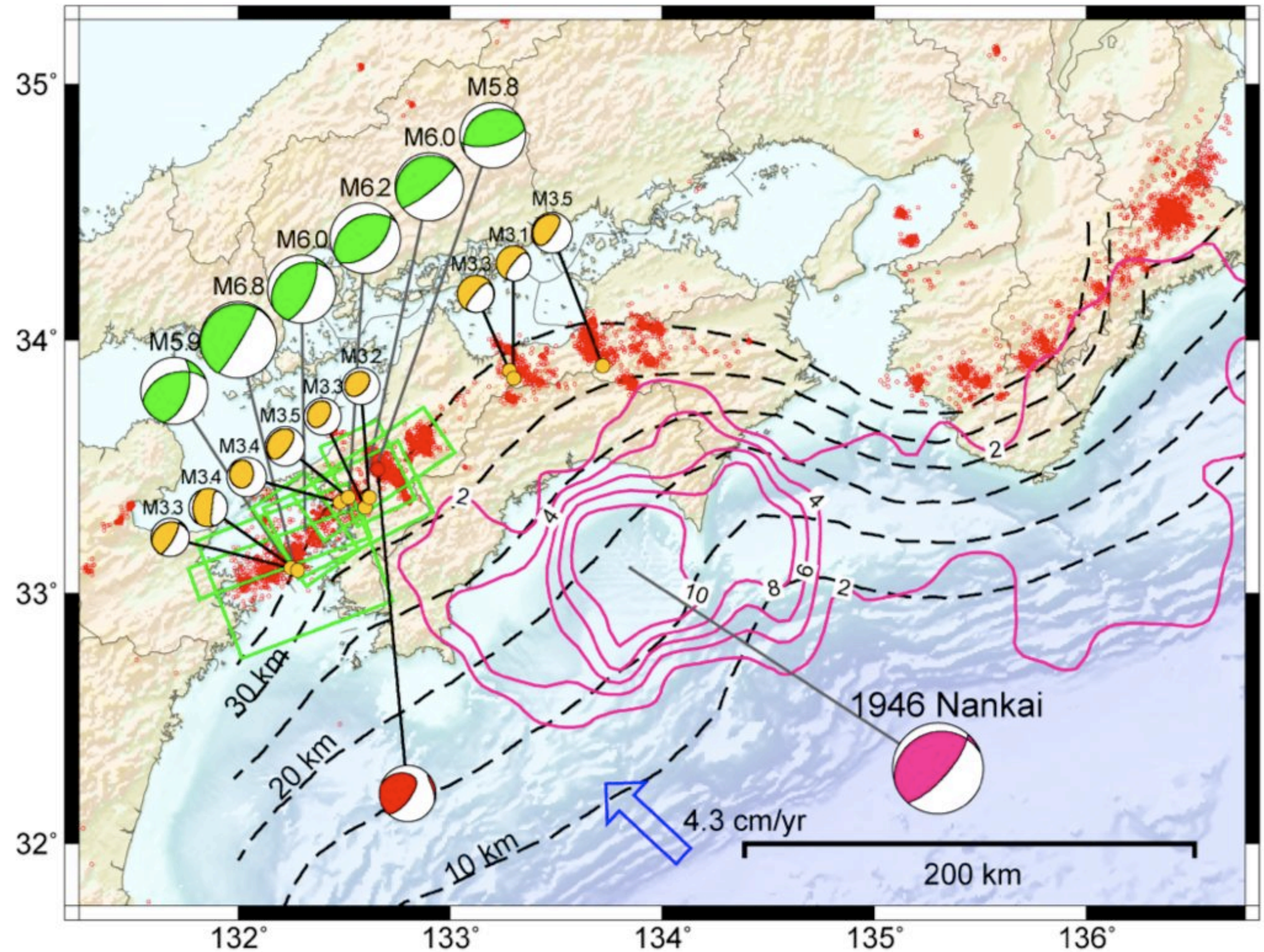
Slow shear slip, not fluid flow.





Does tremor in Japan, Cascadia, California, Costa Rica, Mexico, Alaska,… share the same mechanism?

Tremor, VLFs, SSEs - All Slow, Interplate Earthquakes



Tremor, VLFs, SSEs - All Slow, Interplate Earthquakes

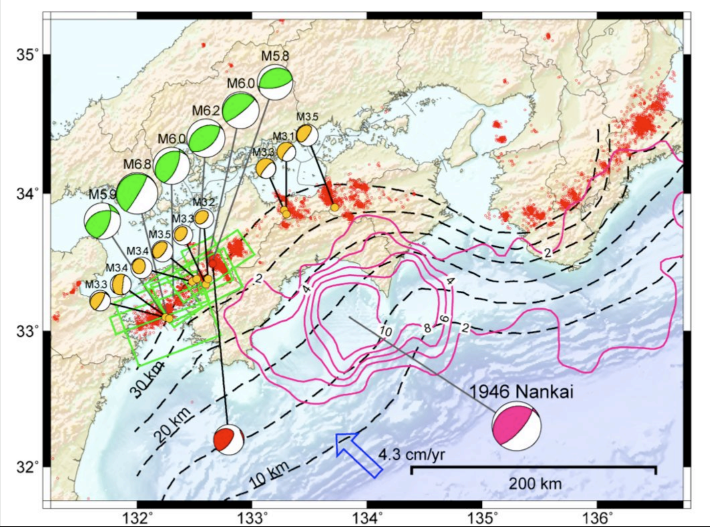
Illuminates the deep roots of faults.

Strategic location - down-dip of locked mega-thrust so it will episodicallly increase stress on the locked zone.

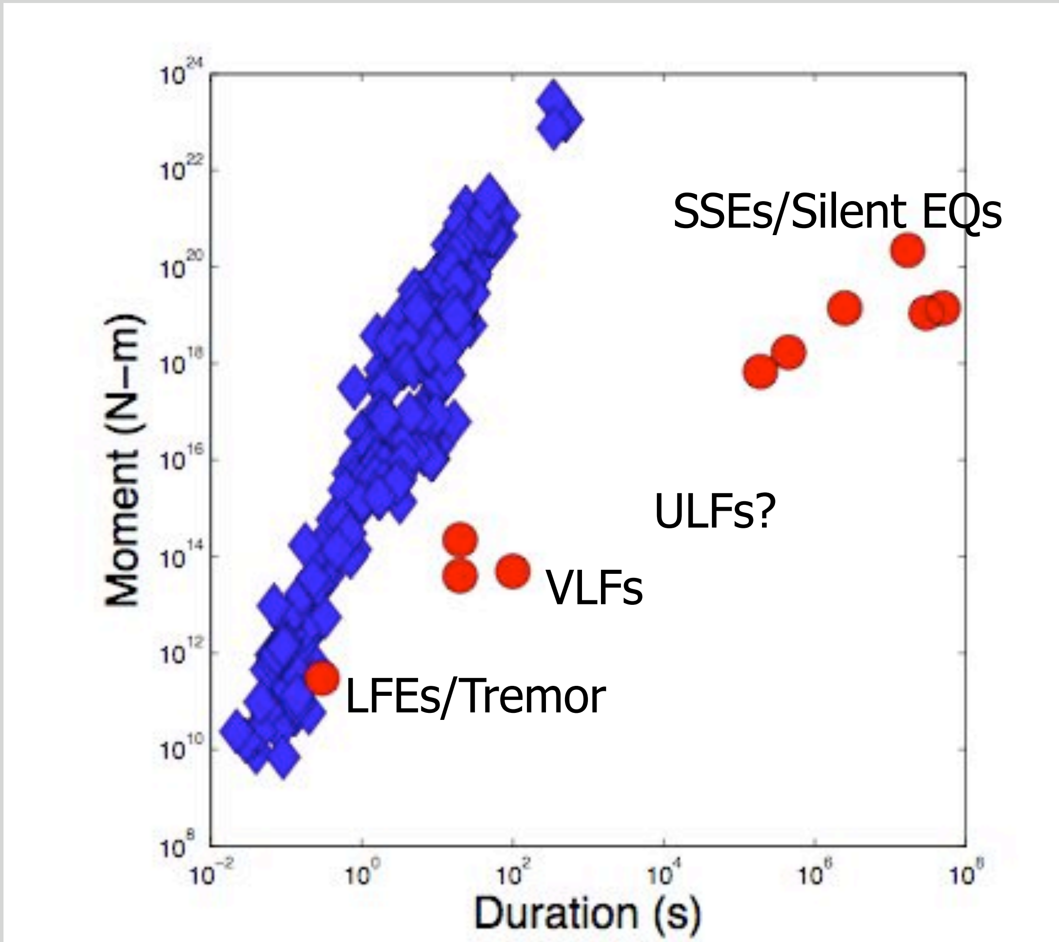
Episodic and protracted process near where large earthquakes are likely to begin.

May outline down-dip transition of slip in large earthquakes - important for ground motion prediction.

Occurs frequently and regularly.



Slow Earthquake Scaling



Why is M_o ~ Duration for slow earthquakes?

Strong Ground Motion Prediction

Need to understand source physics.

Seismology is critical, but other info needed.

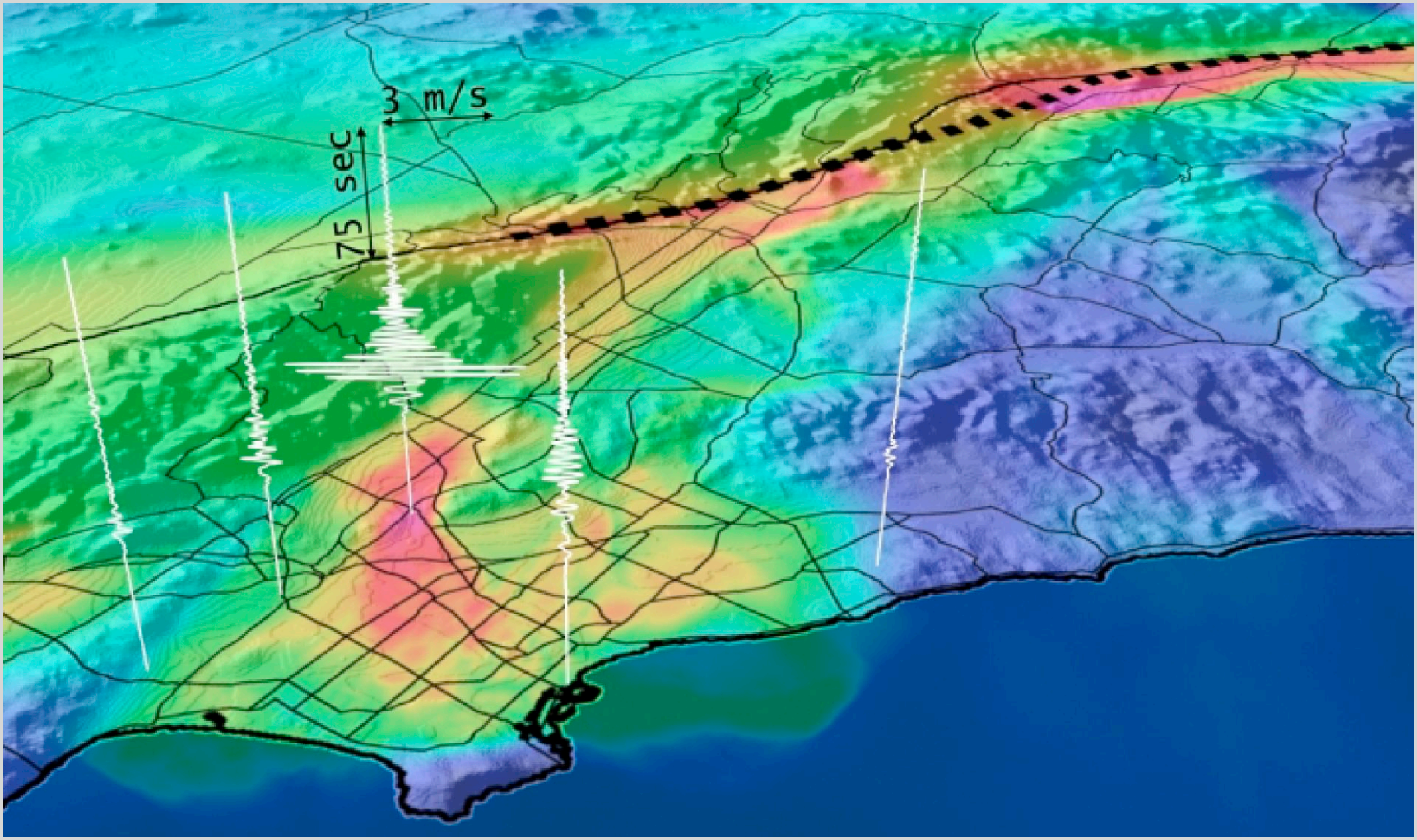
Will allow us to explore range of possible behaviors.

Data needed for validation.

Will allow us to predict ground motion and variability.

This is what society needs from us.

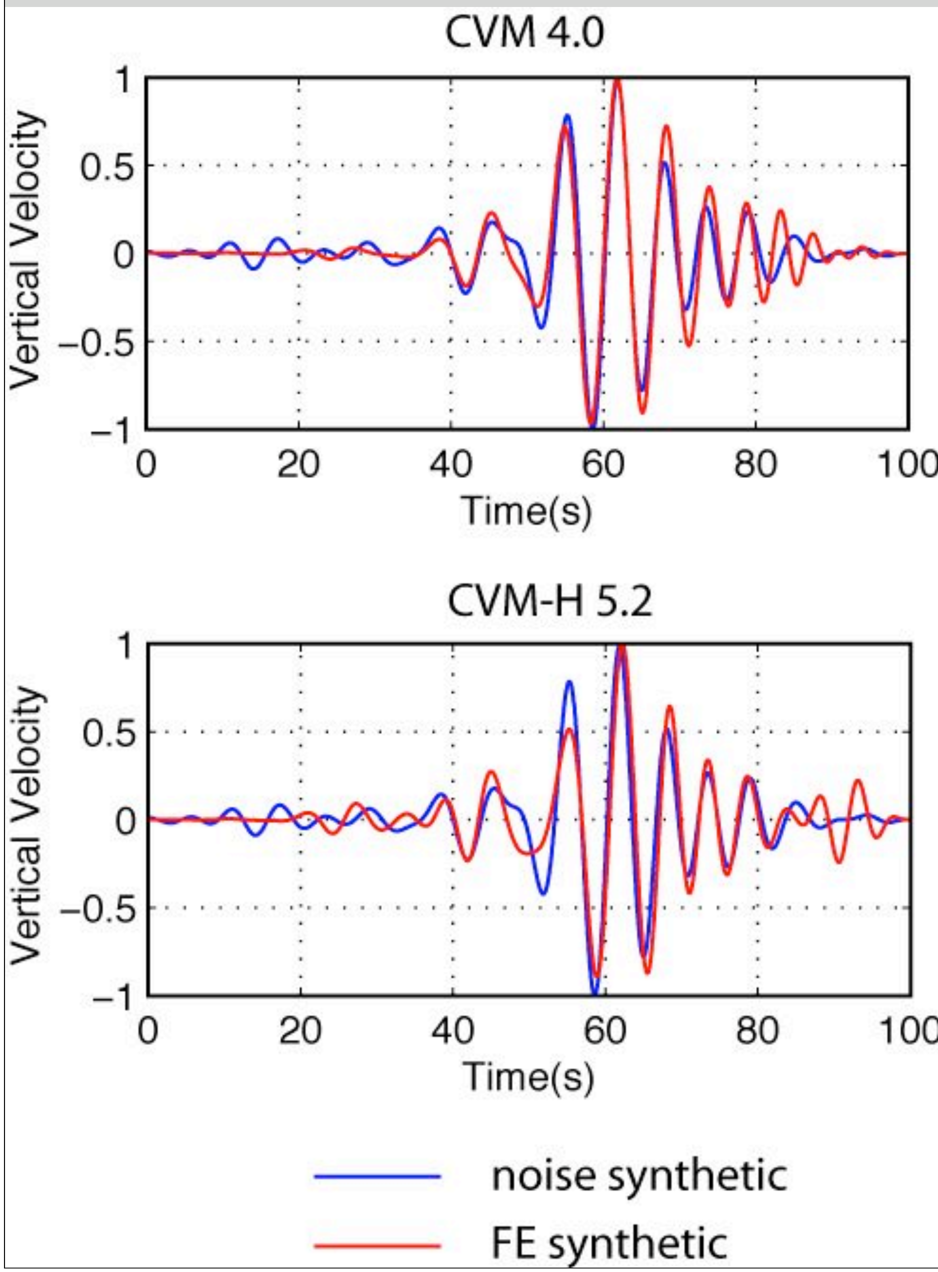
Terashake Simulation



Many sources of uncertainty: source and path effects.

How can we validate these calculations?

Ambient-Noise can be used to Test Predictions

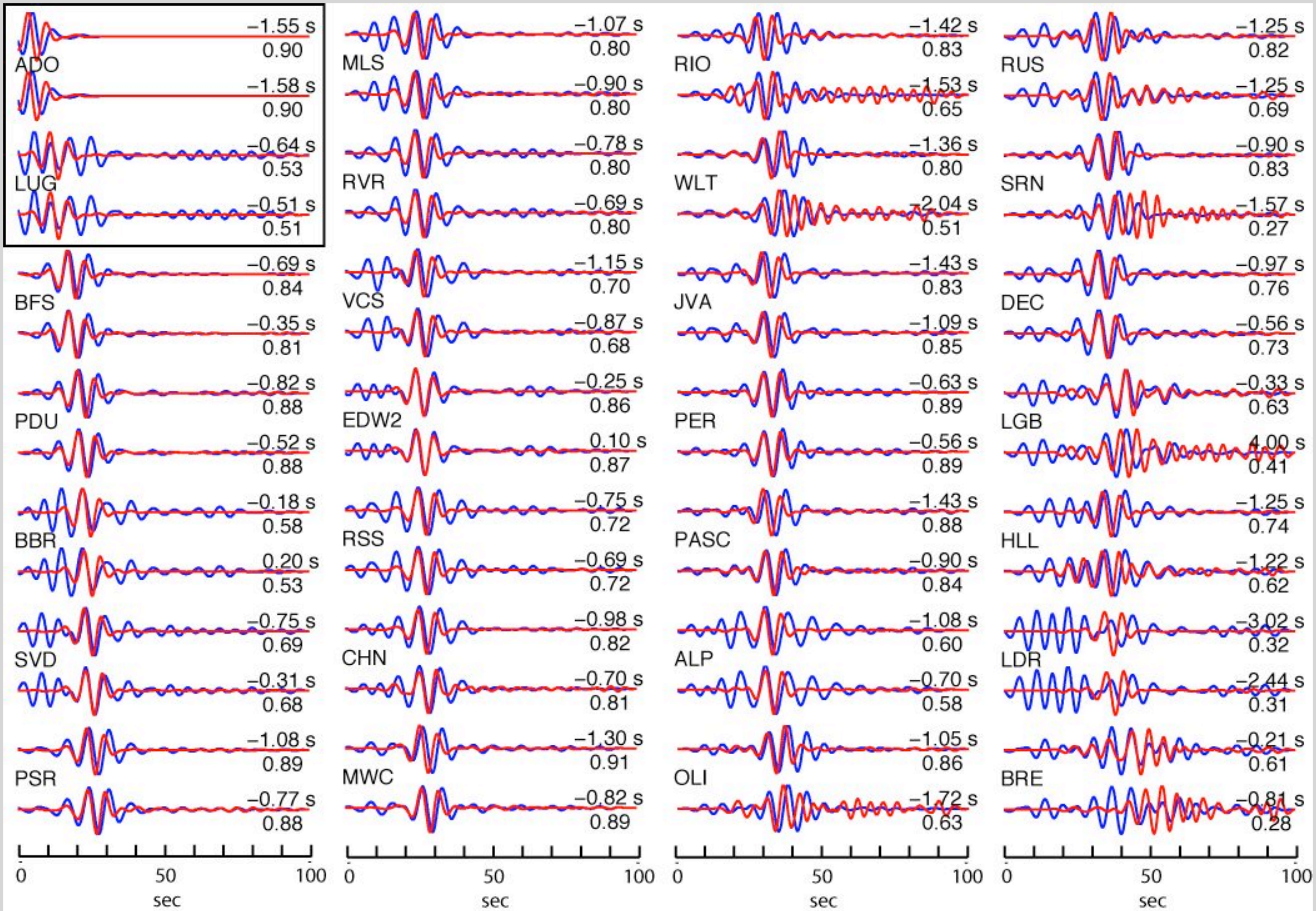


correlation coeff: 0.94
time lag: -0.08 s

correlation coeff: 0.92
time lag: 0.23 s

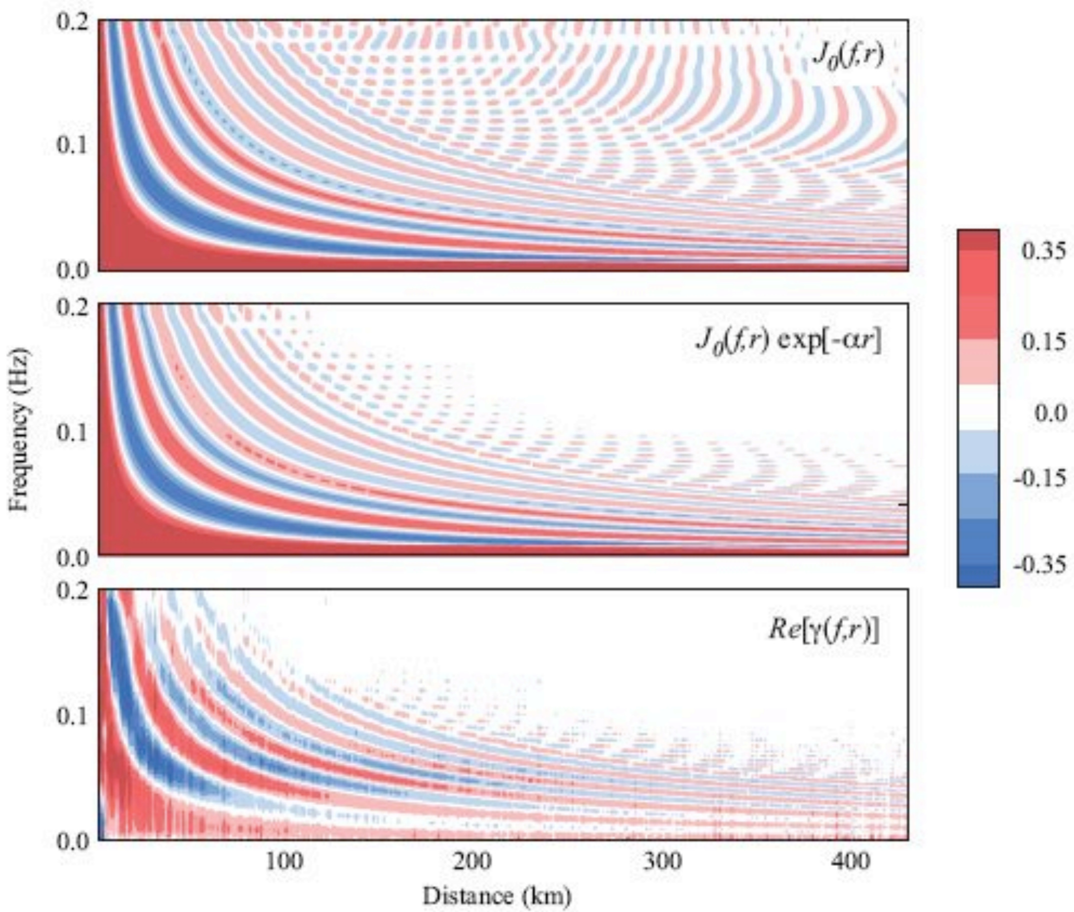
Ma et al. (in press)

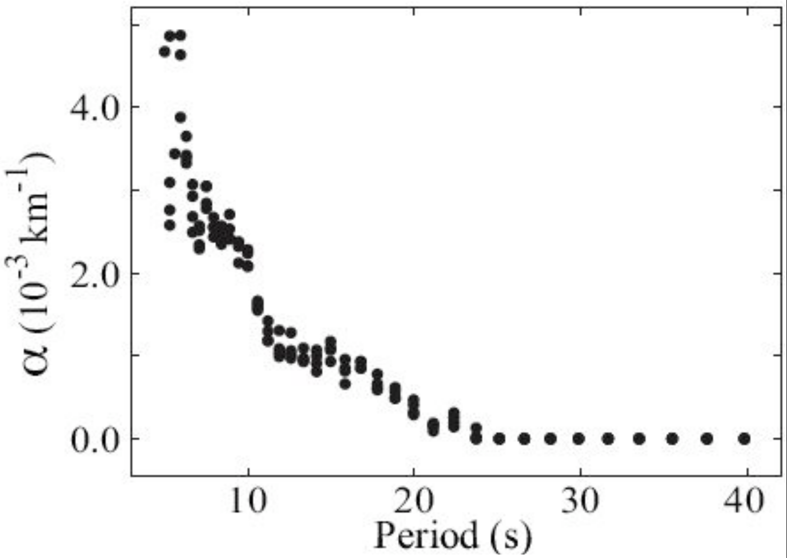
Ambient-Noise can be used to improve velocity models

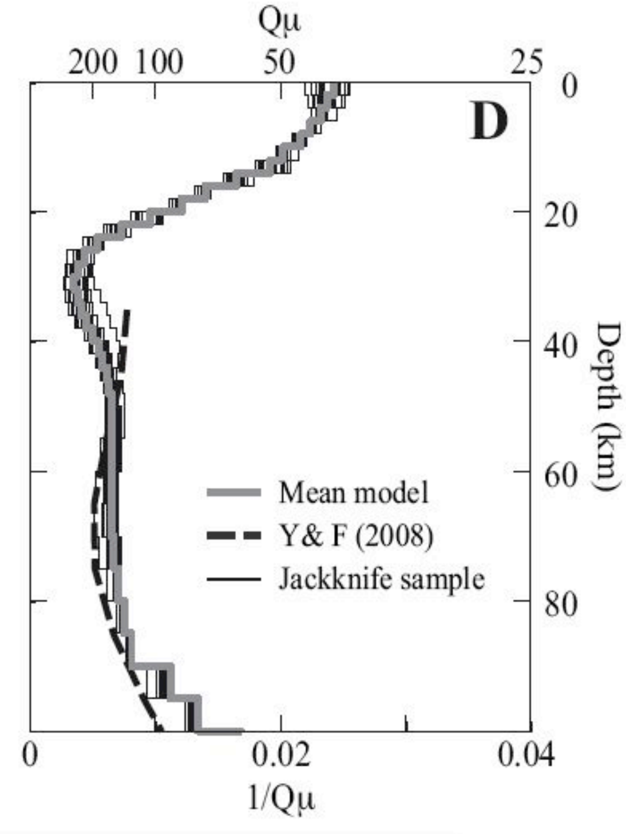


Ma et al. (in press)

Ambient Noise can be used to Measure Q





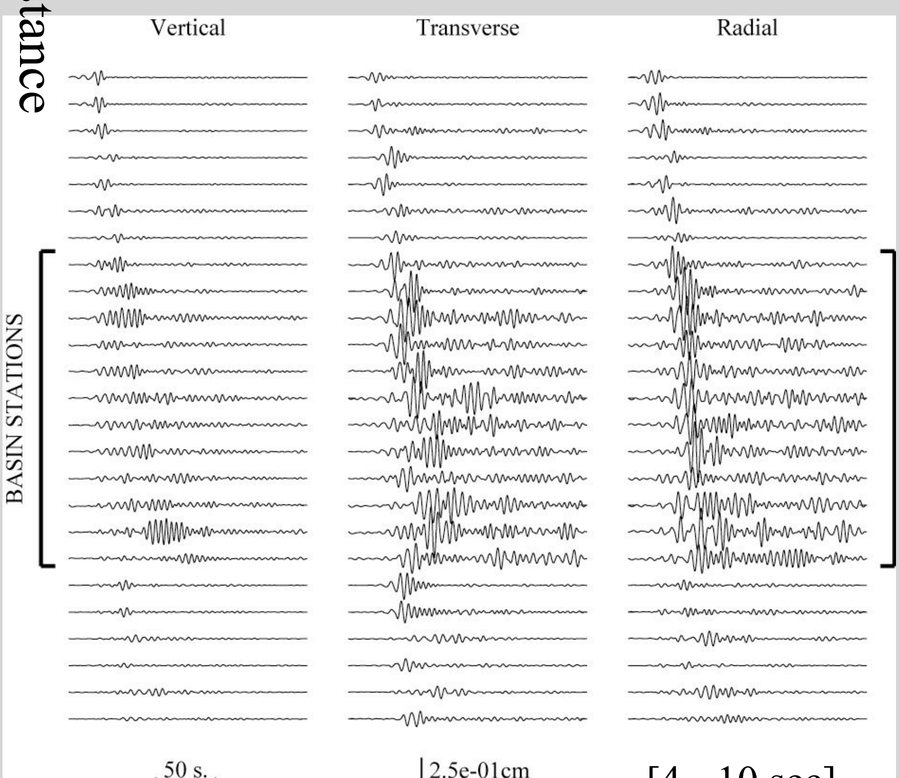


Prieto et al. (submitted)

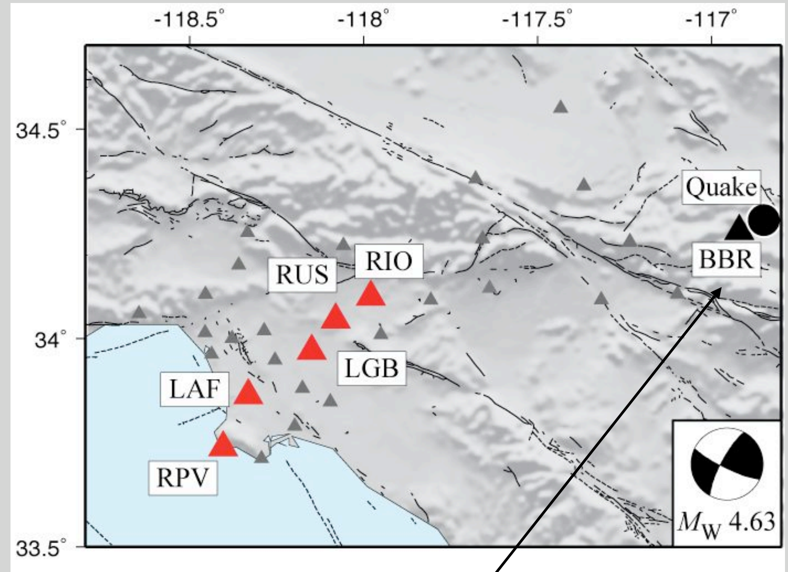
More Direct Tests Are Possible

Earthquake records

Distance



[4 - 10 sec]



10 Feb 2001 M_w 4.6 Big Bear

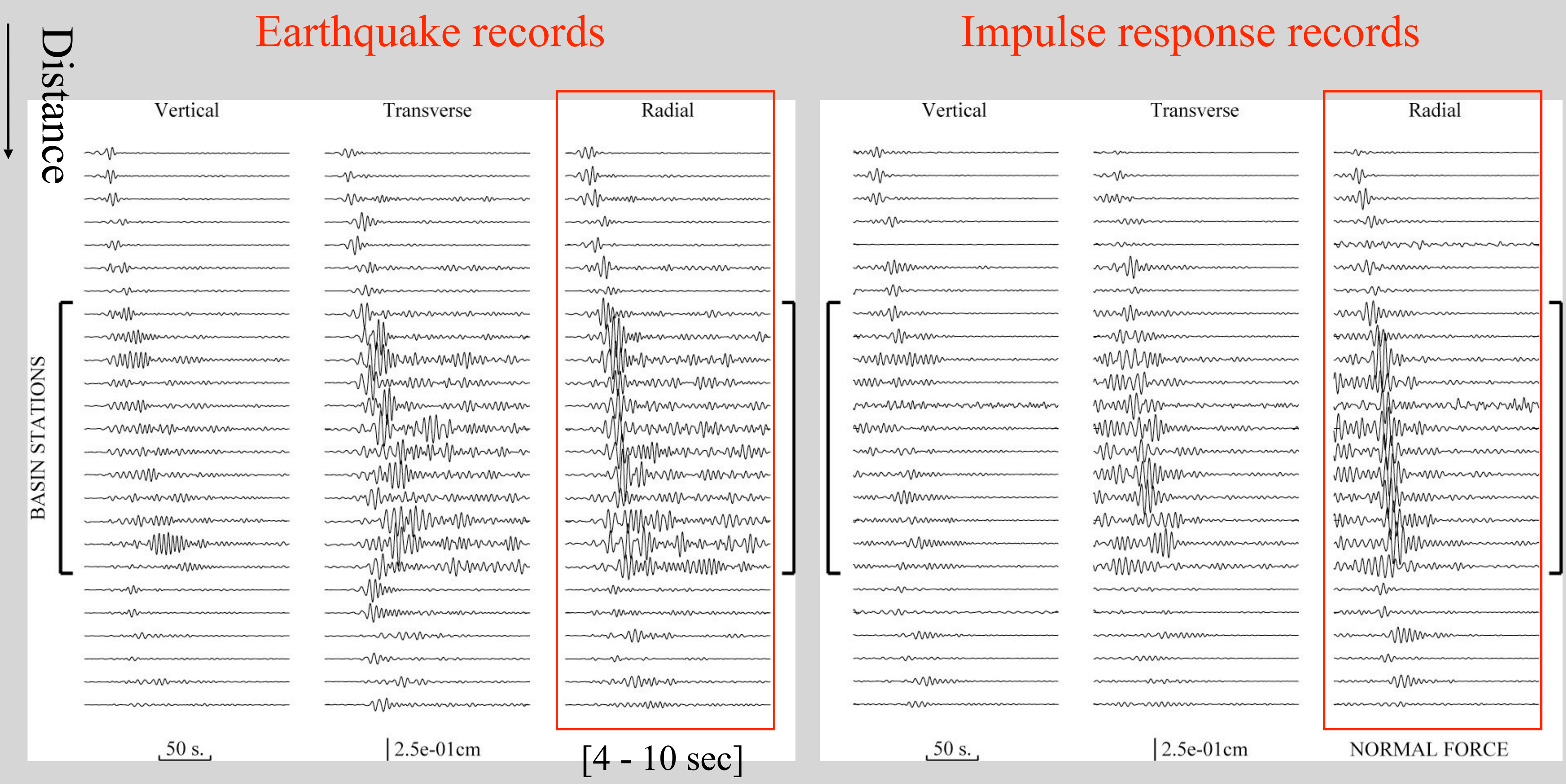
vs. BBR Virtual Source

Graves (2008) studied this EQ too.

Amplitudes in the basin are larger

Prieto and Beroza (2008)

Real vs. Virtual Earthquake

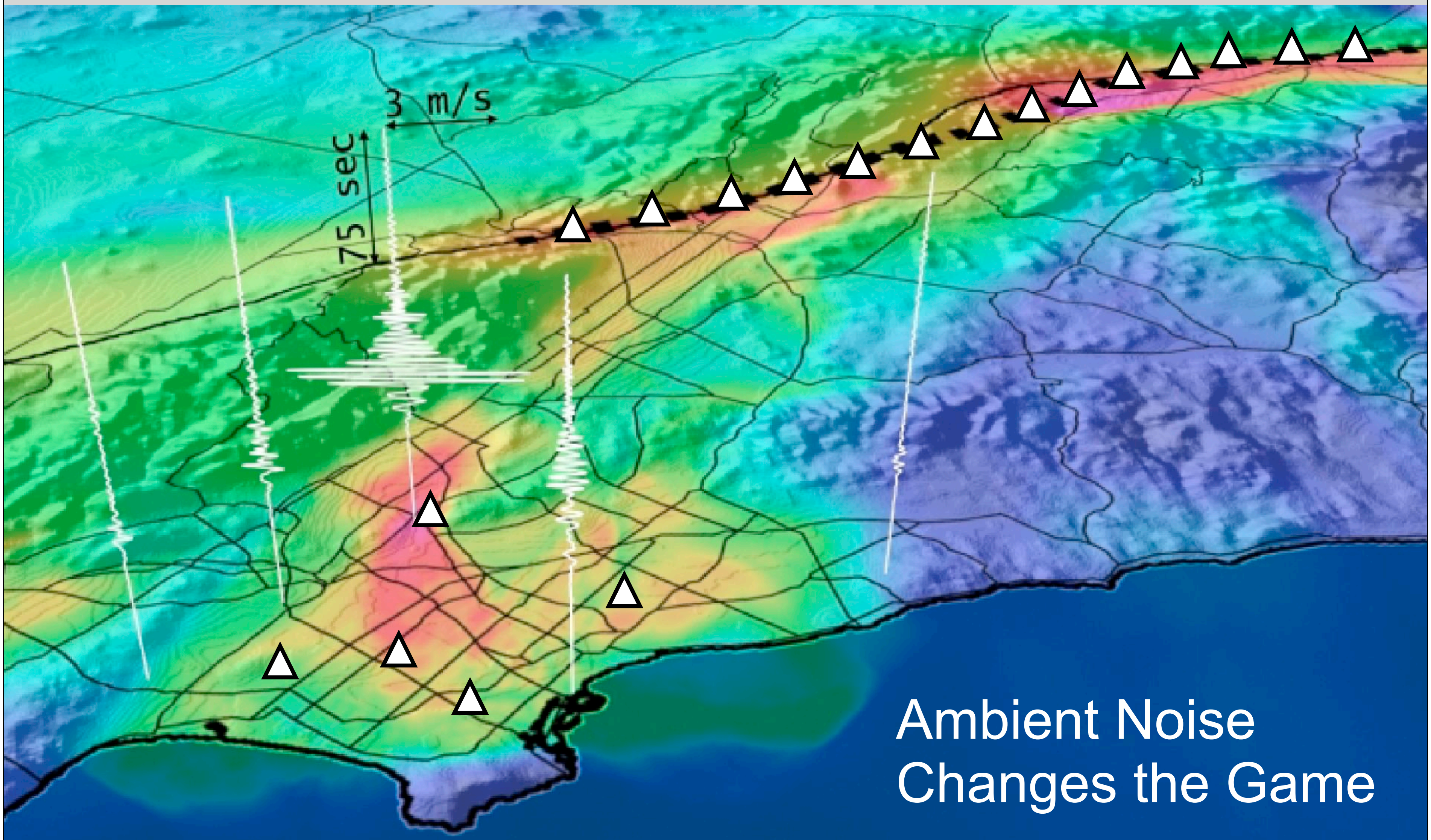


Amplitudes in the Basin are larger

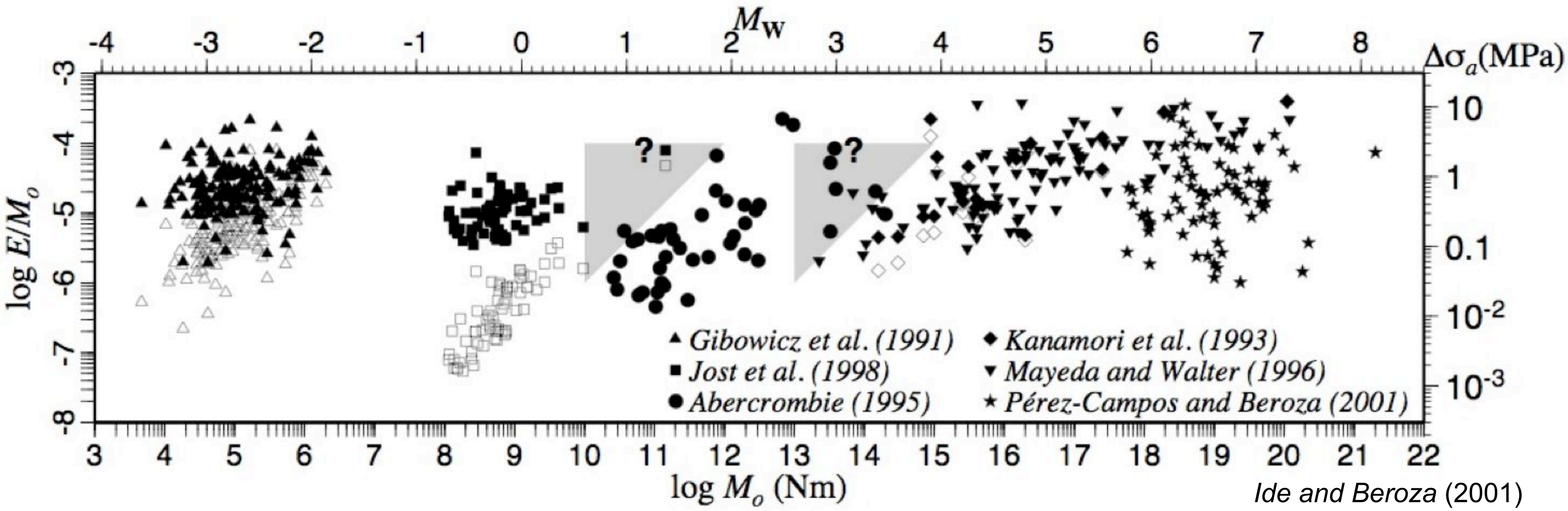
Relative amplitudes are well reproduced

Prieto and Beroza (2008)

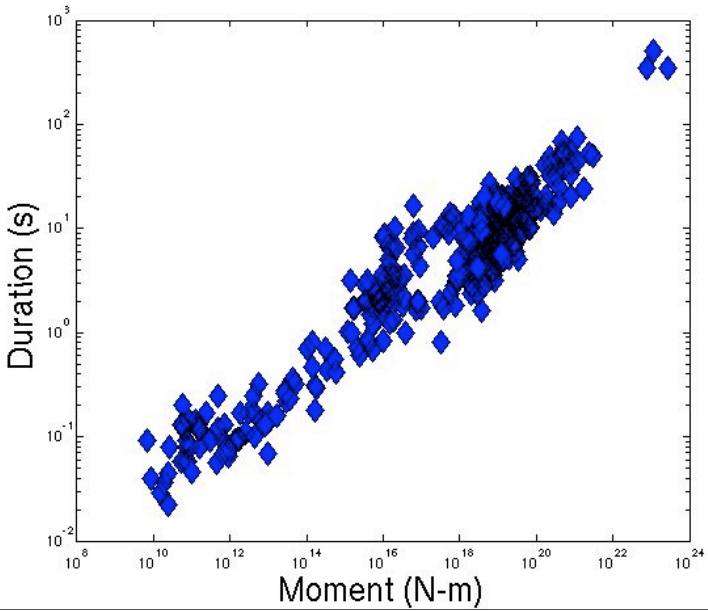
A Possible Seismic Experiment



Need to Understand what's possible from the source



Ide and Beroza (2001)



Systematic variation with size?

Even if not, *huge* variability - is it real?

Consequences for Strong Ground Motion

a_{rms} obeys a relationship of the form:

$$a_{rms} \sim \Delta\sigma \; f_c^{-1/2}$$

Weak increase with M_{o}:

$$f_c^{-1/2} \sim M_o^{1/6}$$

Increase in stress drop with M_{o} would make increase stronger.

Hanks and McGuire (1981)

Super-Shear Rupture in Large Earthquakes

1906 San Francisco (M 7.9)

1979 Imperial Valley (M 6.5)

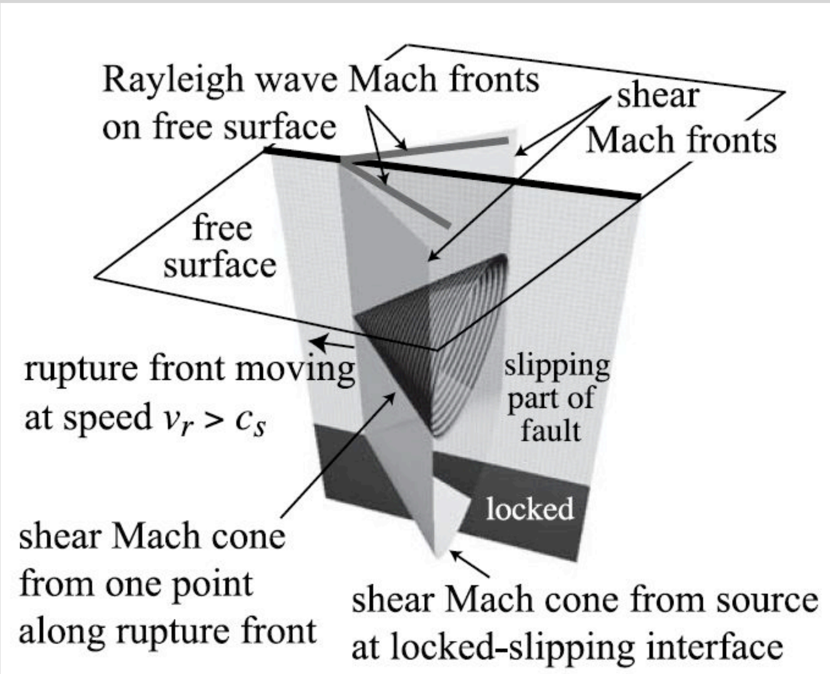
1999 Izmit (M 7.6)

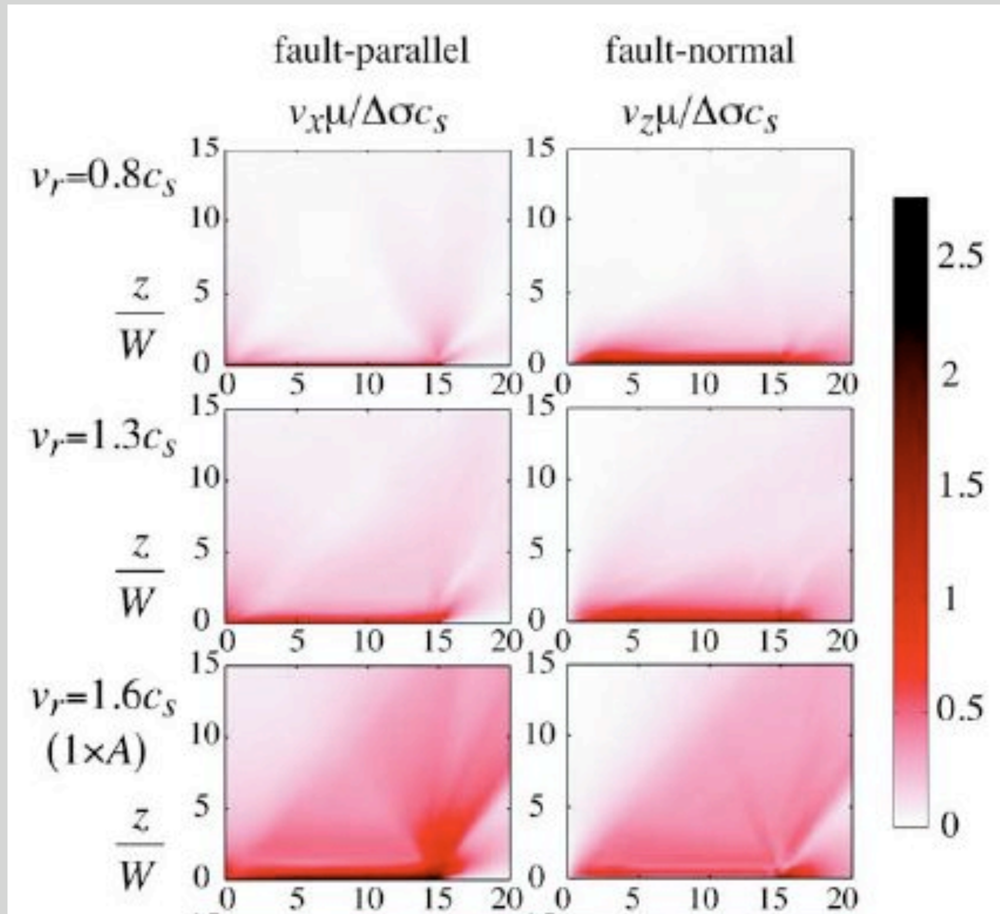
1999 Duzce (M 7.2)

2002 Denali (M 7.9)

2001 Kunlun (M 7.8)

Super-Shear Rupture → Mach fronts





Qualitatively different SGM with larger amplitudes to greater distance.

Dunham and Bhat (2008)

M 6.6 Bam Earthquake

26,000 fatalities

Destruction of World Heritage City

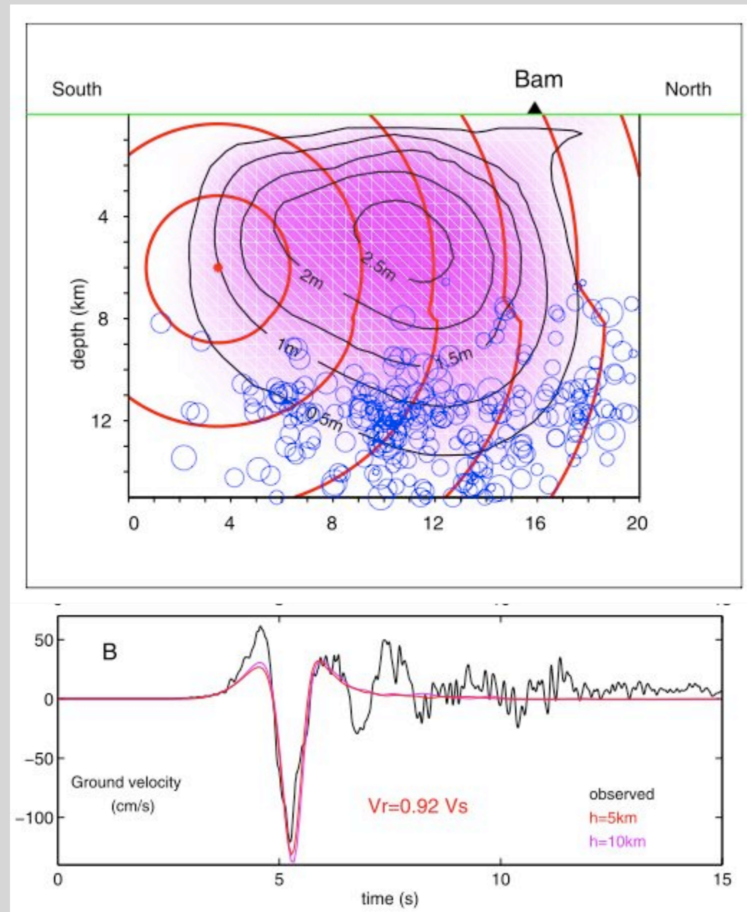
InSAR + seismogram

Requires $v_r \approx C_R$

Extreme Directivity into Bam

After

Before



Bouchon et al. (2006)

We need more strong motion data

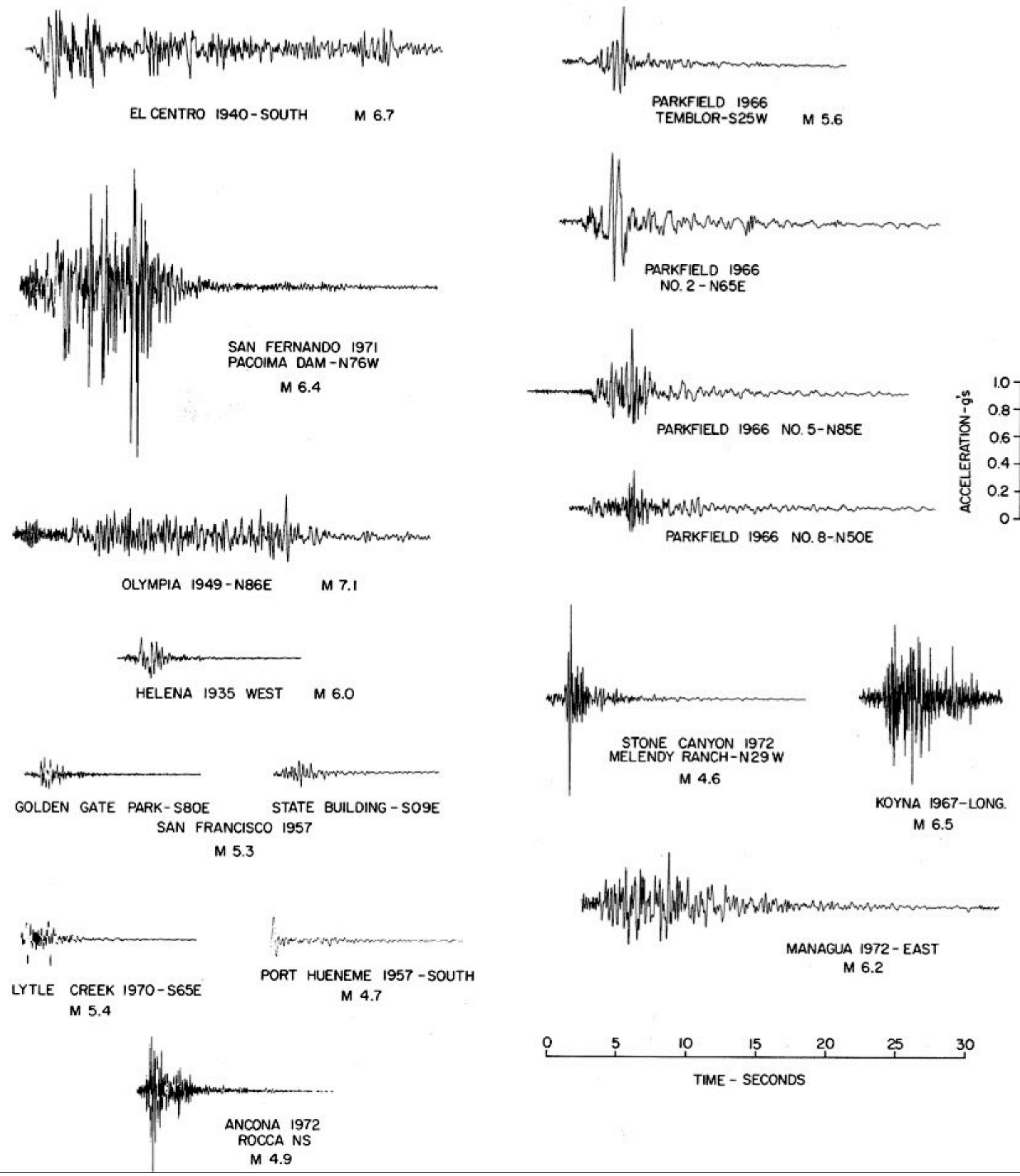
20 years ago, strong motion records were known by name:

El Centro 1940

Parkfield No. 2

Pacoima Dam 1971

…



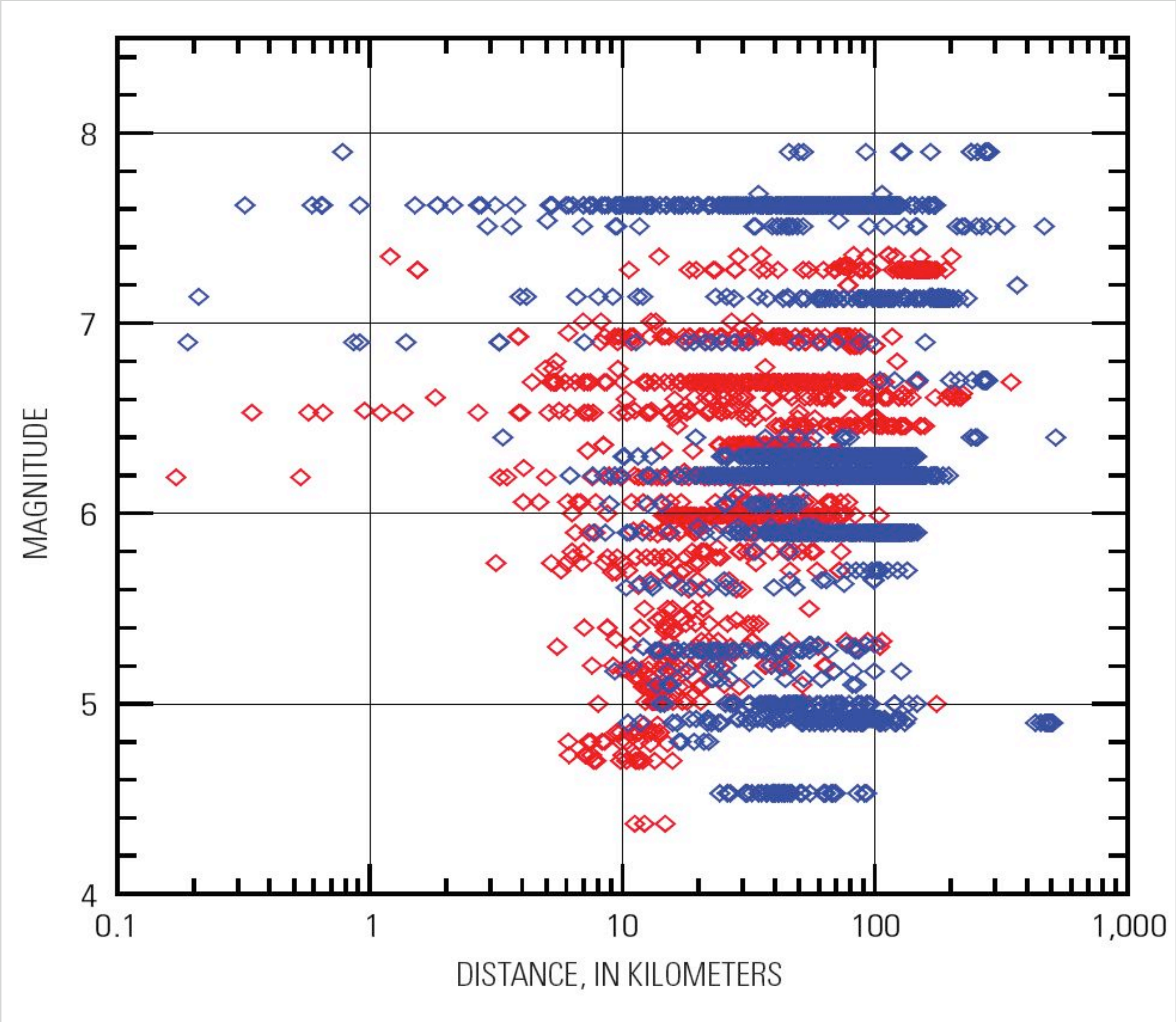
PEER Strong Motion Database

Today we don't know most seismograms by name, but we do know the earthquakes:

Landers, 1992

Loma Prieta, 1989

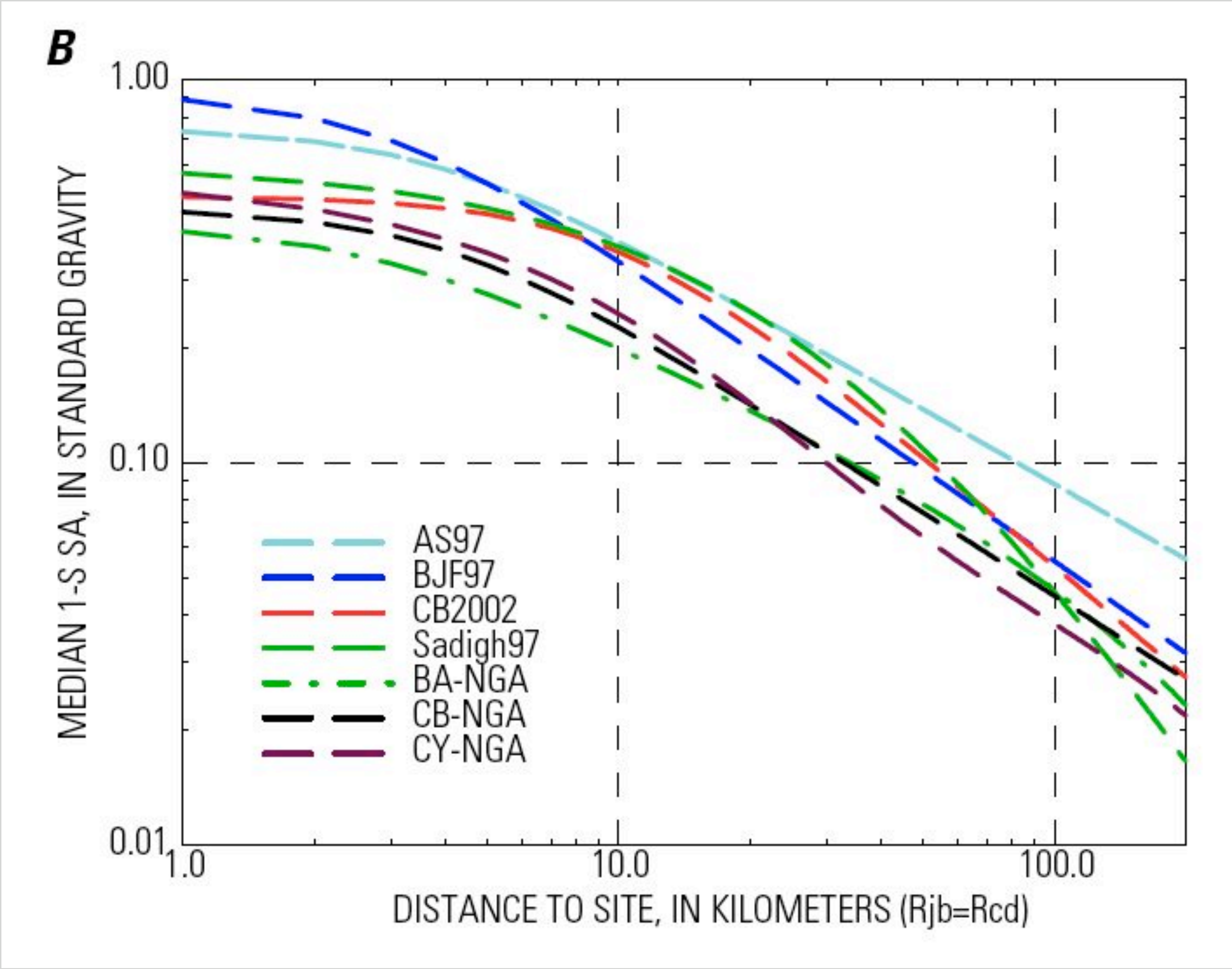
Chi Chi, 1999



New Data

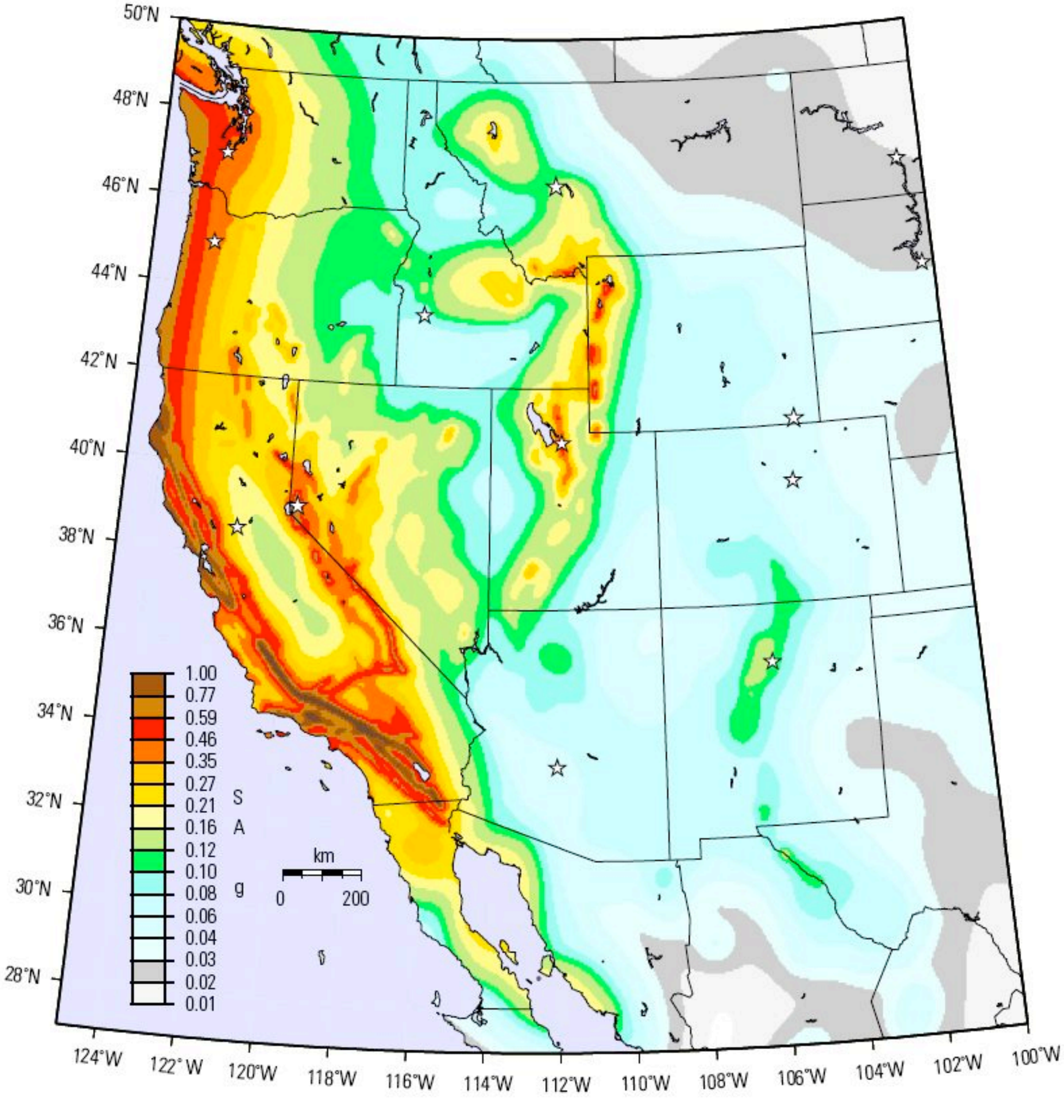
Previous Data

Attenuation Relations for M_w 7.5 Earthquake



All the New Relationships Predict Weaker Motion

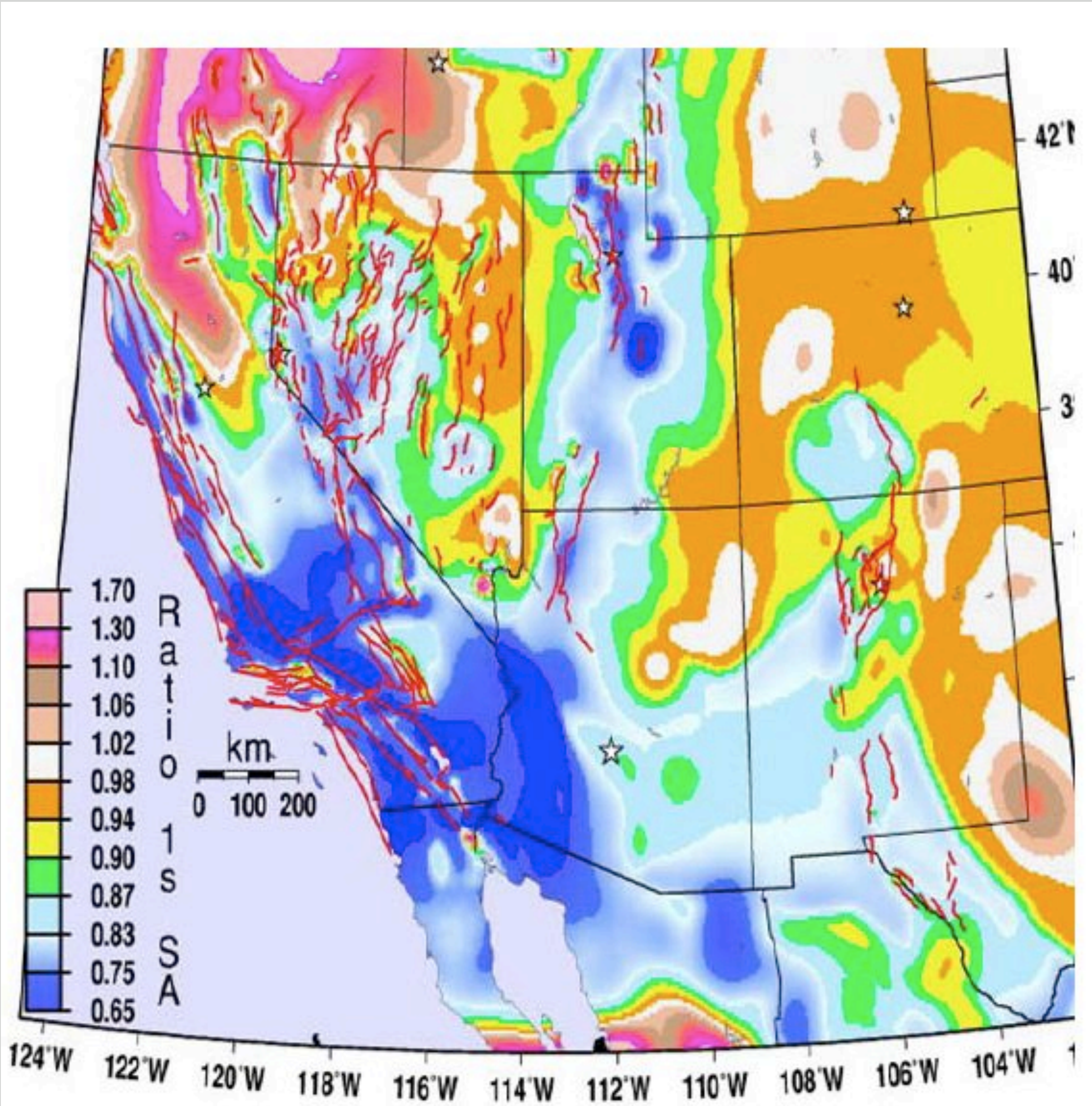
New National Seismic Hazard Map



Ground Motion Intensity

(1 s Spectral Acceleration with 2% P_{exc} in 50 yrs)

Change to National Seismic Hazard Map



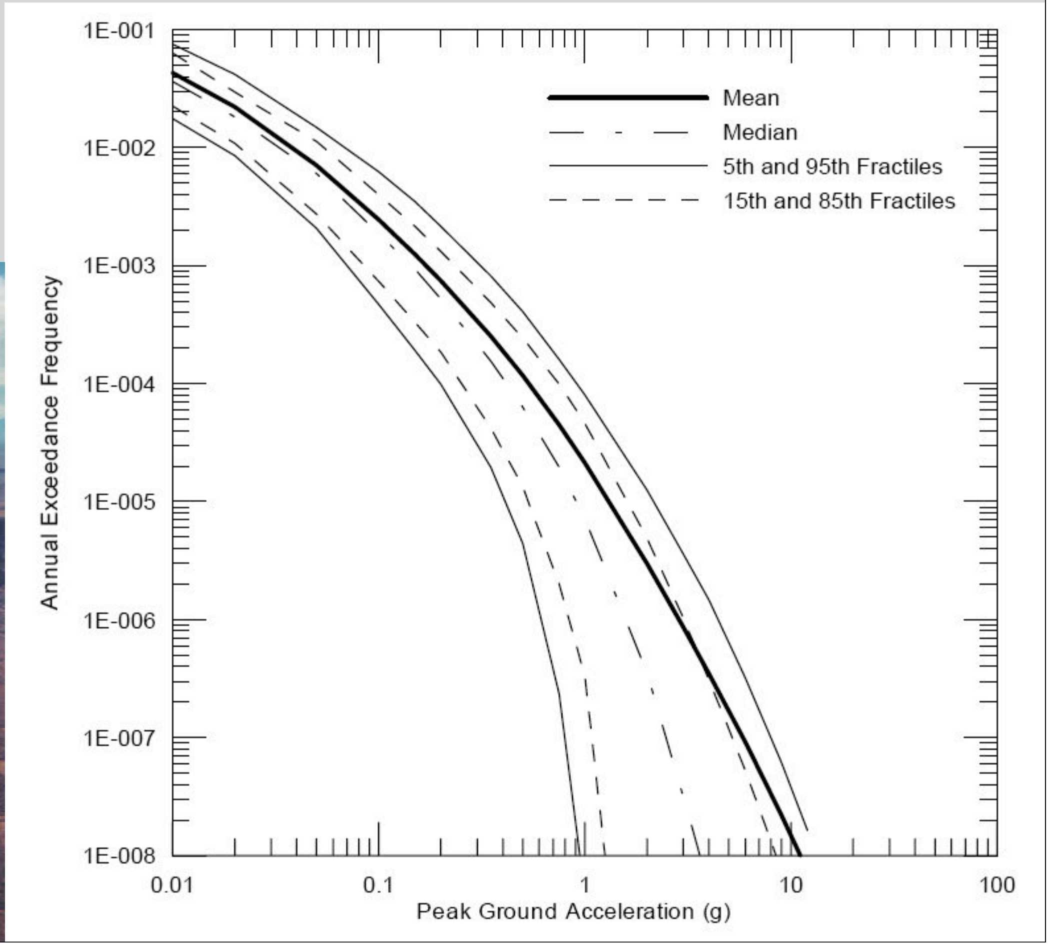
Ratio of New/Old

New design ground motions are, for the most part, less intense.

This is a <u>big</u> deal: will impact $1 trillion in construction over next 5 years.

Yucca Mountain High-Level Waste Repository

Regulatory requirement to consider events with a 10^{-4} chance of occurring in 10,000 years.



Tall (400’+) Buildings

In SF:

- 4 under construction
- 10 approved
- 16 proposed (3 are 1200’ high)

Outside the range of building code provisions.

Ground motions - don’t have much data in close to very large earthquakes

Kashiwazaki-Kariwa Nuclear Power Plant

Power Production:

51 Tw-h in 2006

25 Tw-h in 2007

0 Tw-h in 2008

Shut down in 2007

for inspections/upgrades.

July 16, 2007 M_w 6.6 Chūetsu Earthquake

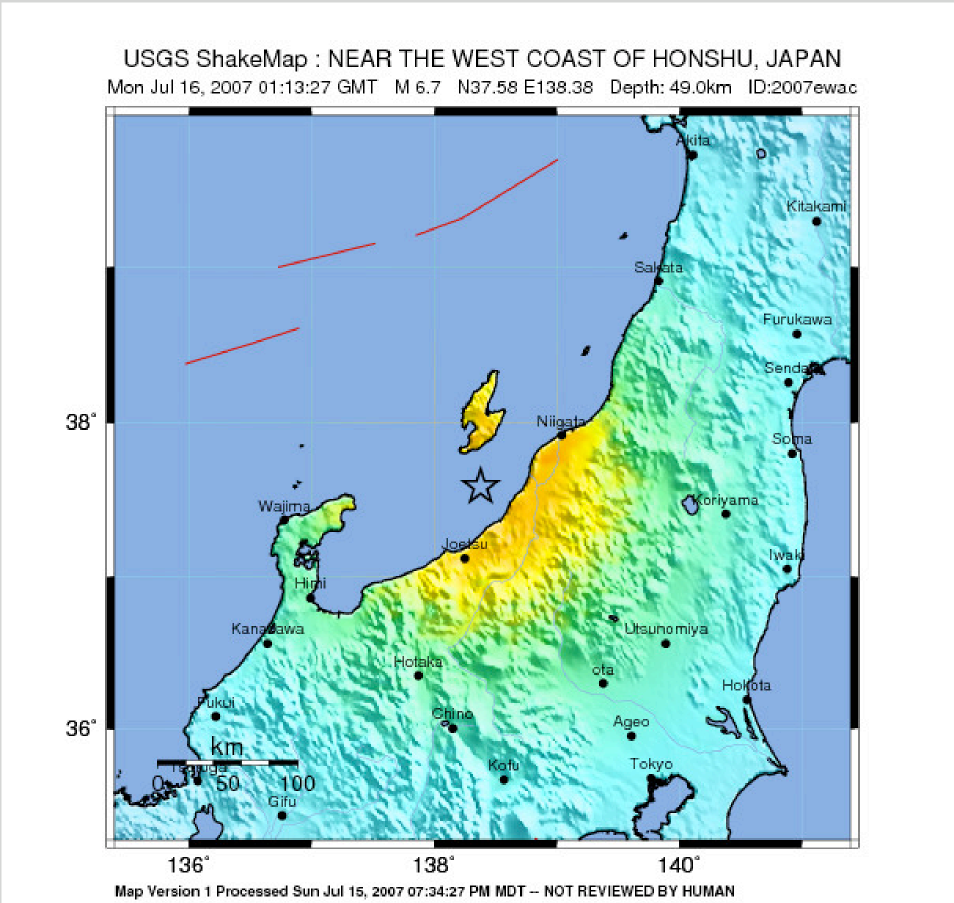
Transformer fire.

Leaks - liquid and gas.

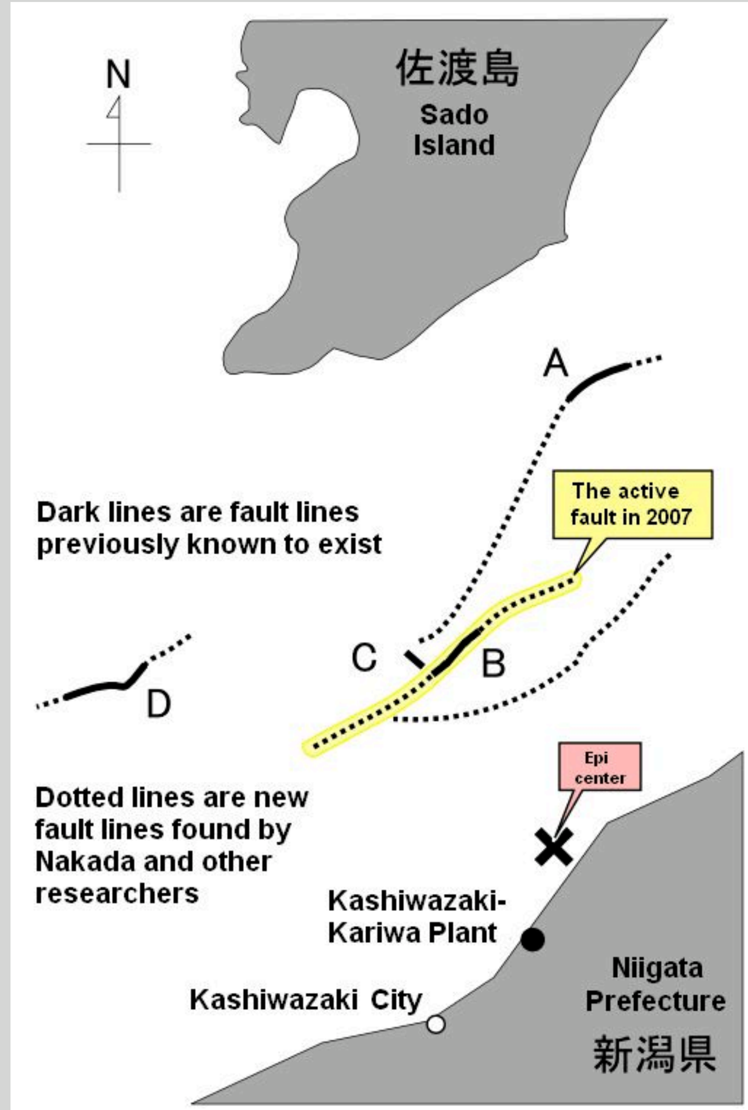
Earthquake exceeded design ground motion.

The reactor remains offline.

July 16, 2007 M_w 6.6 Chūetsu Earthquake



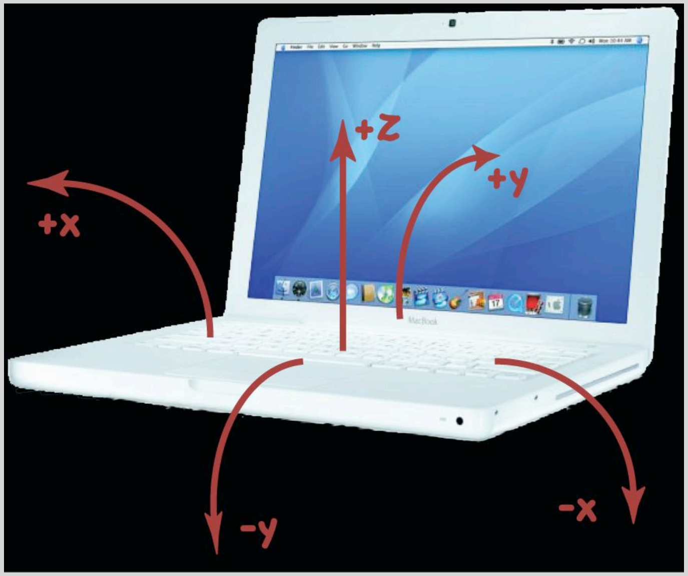
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



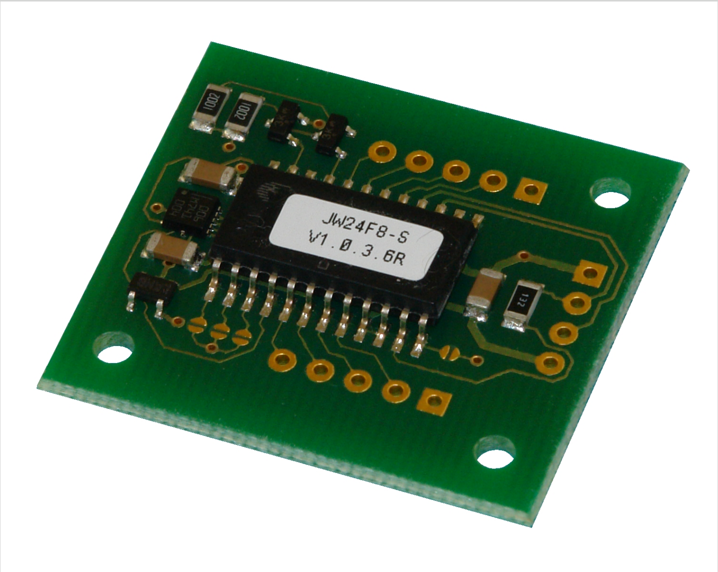
Not even clear what fault ruptured!

Quake-Catcher Network

MEMS accelerometers in laptops, iPhones, Wii remotes, etc.



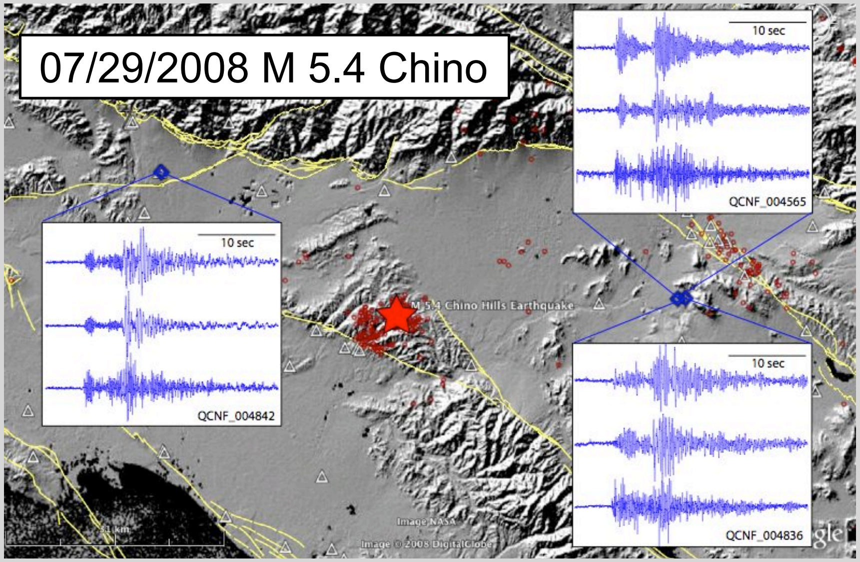
Laptop

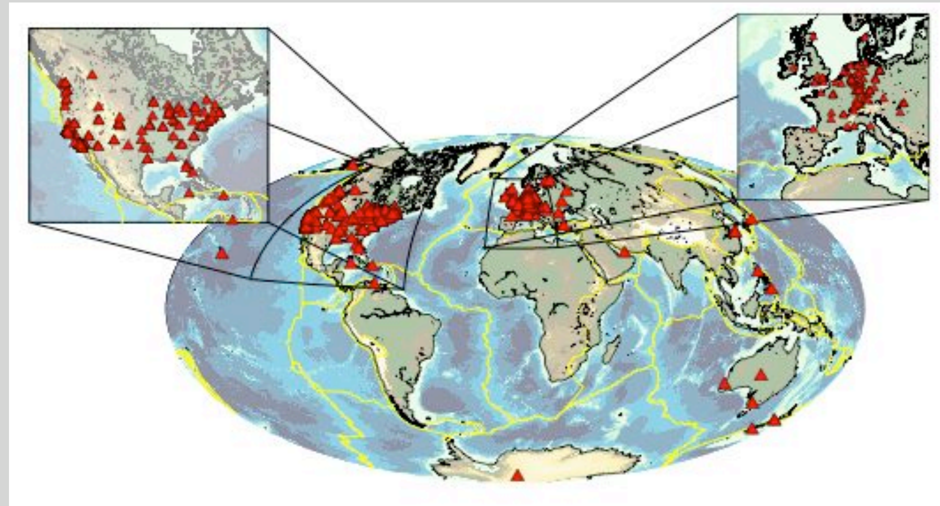


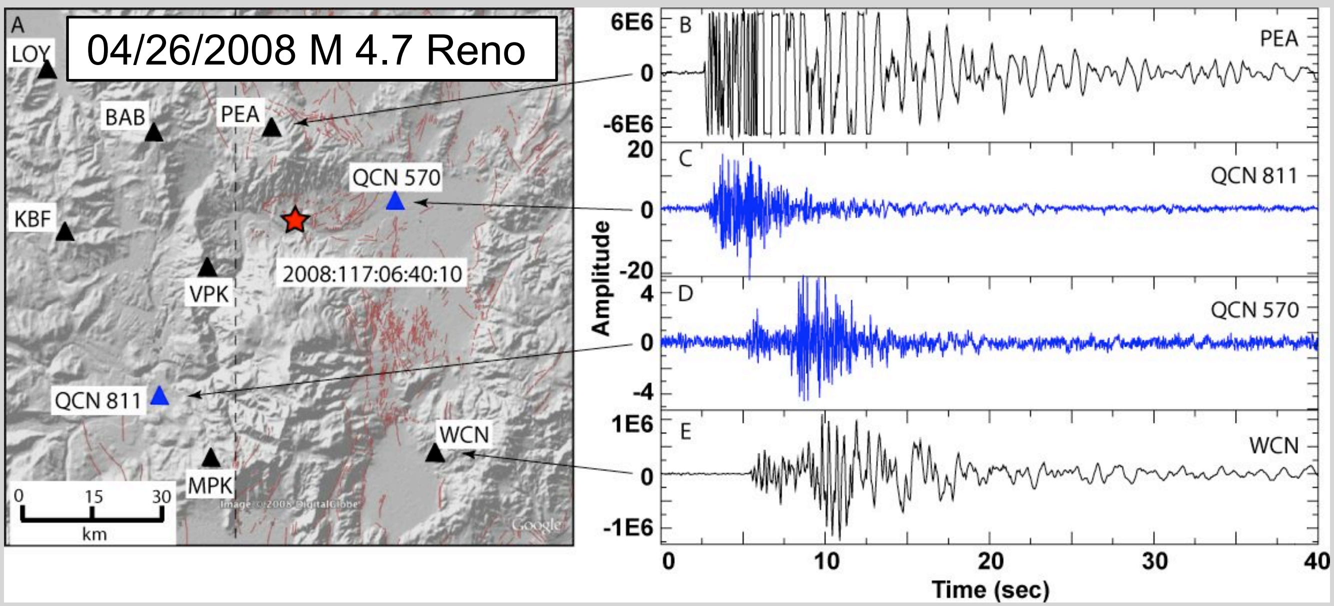
USB Sensor

Jesse Lawrence and Elizabeth Cochrane

Some Recent Earthquakes





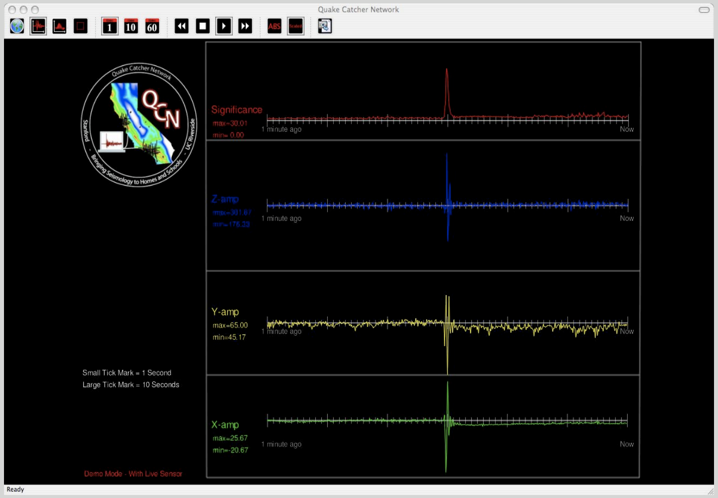


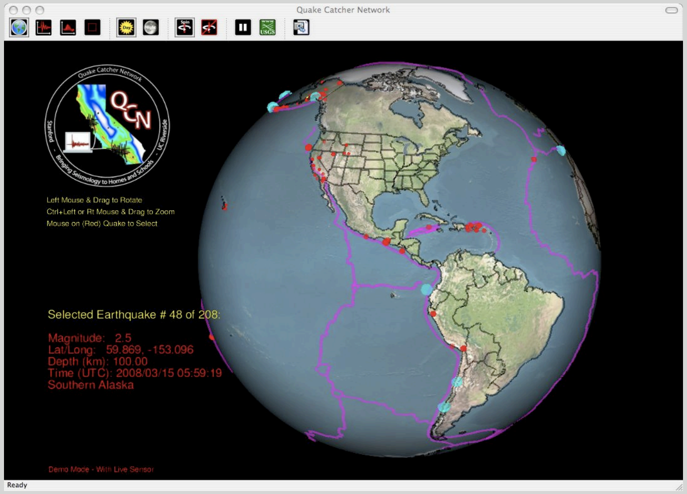
- Detected with laptops
- USB sensors are much better
  - Sensitivity
  - Coupled to floor/ basement (not on table)`

QCN Demonstration

- Demonstration
  - JoyWarrior24F8: ±4mG sensitivity - $30-$50
  - MotionNode Accel: ±1mG sensitivity - $75-$300
  - Laptops: ±4mG to ±40mG - Free
  - Testing & Adding More Sensors

  - Uses < 5% of a CPU with USB accelerometer





Grand Challenge

Develop and understanding of earthquakes sufficient to predict the full range of their possible behaviors:

earthquake size	rupture velocity
rupture direction	slip velocity
slip variability	“recurrence” interval

Translate this understanding into accurate earthquake forecasts, as well as prediction of strong ground motion, and its variability.